XVIII. *On the Ice formed, under peculiar circumstances, at the bottom of running Water.* *By the Rev.* JAMES FARQUHARSON, *of Alford, F.R.S.*

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ICE formed at the bottom of rivers and streams, frequently in great quantities, is a phenomenon quite common in this climate. I made for several years past a number of incidental and desultory observations upon it, and became convinced that the principal explanation of its occurrence is the radiation of heat from the solid opake materials of the bottom; but as I conceived this to be also the generally admitted one, I took no note of the observations, with the view of vindicating the theory of the radiation. It appears, however, from a paper of M. ARAGO upon the subject, translated and published in the Edinburgh New Philosophical Journal, vol. xv. p. 123, from the Annuaire for the year 1833, that he entirely rejects the theory of the radiation of heat through a thick layer of water. In the same paper, although he does not, in conclusion, pretend to give a complete explanation of the phenomenon, he brings forward, as explanations in part, three circumstances, which, although accurately stated by him, appear to be not exclusively appropriate to ice formed at the bottom, and cannot therefore aid us in solving the main question which we have to discuss here, which I apprehend to be, *Why is ice formed sometimes on the surface of running water, and sometimes at the bottom?*

On reading M. ARAGO's paper, I became desirous of offering some remarks in answer to it, as without some one doing this, on proper data, a misapprehension concerning the cause of a natural phenomenon, so much at variance with our most frequent experience of the formation of ice only on the surface of all waters, as to have often greatly excited the attention and even called forth the astonishment of scientific men, would continue to be propagated under the authority of a distinguished name. Having, however, no record of my former observations to enable me to refer accurately to the time, place, and other circumstances of them, I delayed till a renewed occurrence of ice on the bottoms of our streams should enable me to repeat them.

Such an occurrence, on a great scale, took place in the beginning of this month of January (1835); and I now have the honour of presenting to the notice of the Royal Society a brief account of the observations I have been enabled to make, and of the conclusions to which they appear to direct us.

Previously to entering on this detail and discussion, it seems proper to describe the appearance and quality of the ice formed at the bottoms of streams. A misapprehension regarding these may have been one cause of the incredulity of its existence,

entertained by some persons who have never witnessed it, and which M. Arago, in the paper referred to, has deemed it necessary to remove, by bringing forward the testimony of many distinguished men to its reality. The ice formed at the bottom does not resemble the solid glass-like plates which are formed on the surface. It has nearly the aspect of the aggregated masses of snow as they are seen floating in rivers during a heavy snow shower; but, on taking it out of the water, it is found to be of a much firmer consistence than these, although never approaching to the firmness and solidity of surface ice. It is a cavernous mass of various-sized, but all small, pieces or crystals of ice, adhering together in an apparently irregular manner by their sides, or angles, or points, promiscuously. Both the firmness of the adhesion and the dimensions of the interstices (the latter filled with water, and their volume easily estimated by the quantity of it which is discharged when the ice is lifted out of the stream,) are, however, greatly modified by the intensity and continuance of the previous cold. When the ice begins first to form on the bottoms of the streams, it presents a rudely symmetrical appearance, which, for illustration, may be compared to little hearts of cauliflowers, fixed on the bottom, having a similar uniform circular outline and protuberance in the centre, with coral-like projections. These pieces have a shining silvery aspect; they are dispersed, at first irregularly, in small numbers, but increase both in size and numbers, till the whole bottom is covered, and, if the frost continues severe, grow in height, but in a very irregular manner, so as to obliterate the earlier somewhat symmetrical shapes, till the streams are raised high above their former levels, and frequently made to overflow their banks. And here I take the opportunity to notice the incorrectness of an observation of Desmarest, quoted by M. Arago, and which, M. Arago observes, no one has corroborated, "that it was from the lower parts, which touched the bottom, that the flakes of ice successively increased." On the contrary, the forms of the surface of the earlier masses are continually obscured, in succession, by new ice added to the top.

This congealed mass being thus very different in appearance and consistence from the sheets or plates generally known by the name of ice, it were no doubt well that, like the Germans, who, M. Arago informs us, name it *grundeis*, we too designated it by another name, to prevent confusion or misapprehension when we refer to it. The inhabitants of this part of the country will furnish us with a better one than even that of the Germans. In a district where it occurs almost every winter, and often repeatedly during that season, and where many of the rivers are crossed by means of fords, its existence influences too much their economical arrangements not to excite their particular attention, especially as many horses refuse to enter any stream even slightly impeded by it, being greatly alarmed by the pieces which break and float up from the bottom by the action of their feet. A body with which all are so well acquainted is known by an appropriate name. They call it *ground-gru*; *gru* being the term by which they designate snow saturated with, or swimming in water. I shall venture to use their term for the ice formed at the bottom.

It will be better here also to state, generally, the conditions of temperature and phases of the weather under which the ground-gru is formed. I have seen it occur only when the temperature of the whole mass of water was reduced to, or nearly to, 32° FAHR., and when the temperature of the air was several degrees below that point. I have observed it an invariable condition, that it was preceded by a continuance, for some time, of a clear, or very nearly clear, state of the sky. This is at variance with another observation of DESMAREST, quoted by M. ARAGO, that "when, in consequence of a cloudy sky, the atmospherical temperature experiences little variation throughout the day and night, the ice at the bottom of the water uniformly increases every twenty-four hours; on the contrary, when the sun shows itself, the ice does not increase during the day." It is the fact, that while it is forming under the continuance of a cloudless sky, its increase is impeded during the day. It may be possible, amidst the infinite variety of measures of cold that may exist at the time, that the increase of the gru may go on for a little time after the sun has been obscured by a thin cloud; but I have always seen, that when a densely clouded state of the sky supervened, and continued for the space of even only twenty-four hours, the gru became detached from the bottom, and floated down the stream. Should the temperature of the air continue low, with the clouded sky, or get lower, the ground-gru is not renewed, but the river is speedily frozen over at the surface. It is, in fact, a matter of frequent occurrence, in frosty winters, that our rivers, filled, and so impeded, by ground-gru, as to be raised above their banks, are found returned into their natural channels, and there frozen over at the surface, but flowing over a clear bottom, in a space of time so short as to appear very wonderful to those who have not investigated the cause. The process is named, by the country people, the *flitting* of the ice. In opposition to the observation of DESMAREST, and in confirmation of those which I have made, on this point, I may refer to the Rev. Mr. EISDALE, who, not satisfied with the explanations of M. ARAGO, has published one of his own, in the Edinburgh New Philosophical Journal, vol. xvii. p. 167. His explanation appears equally unsatisfactory, as will be shown afterwards; but the part of his statement we have to do with here is his notice of this observation of DESMAREST. The formation of the ground-gru, under a cloudy sky, is so much at variance with the information which Mr. EISDALE had received, that he resolves DESMAREST's "cloudy sky" into "an atmosphere loaded with hoar frost, and rendered hazy by its condensation *." The state of the air, in respect of being windy or calm, deserves also to be noticed. The ground-gru occurs most frequently during calm, with a deposition of hoar frost upon the ground at the time; and this was the condition of matters during the observations now to be detailed. But it also occurs during a frosty wind, when there is no hoar frost, which is formed only in a calm state of the atmosphere. The formation of the gru during wind, and consequently without any deposition of hoar frost on the ground, is especially to be noticed in reference to Mr. EISDALE's explanation.

* p. 172.

as will be afterwards seen. It occurred to M. Hugi, as quoted by M. Arago, in the Aar, on the 16th February 1827, with a west wind, after the river had been completely open on the 15th; and one of Mr. Eisdale's correspondents ascribed its occurrence in one particular instance, which he related to him, to the prevalence of a very sharp north-east wind, which had blown during the night of its formation.

The following observations were made in the rivers Don and Leochal. The former, having an easterly course, is about 120 feet broad, and a foot or two deep at the shallows and fords. The latter, one of the small tributaries of the former, having a northerly course, is about 20 feet broad, and a foot deep at the shallows. Both rivers possess a like character of very clear water, and alternating rapids and pools. The rapids in the Don are reaches, where the water falls two or three, or more, feet, from a higher to a lower level, within a distance of fifty or a hundred, or sometimes two or three hundred, yards. They are generally impeded with many large stones, some of them projecting above the water. The depth varies greatly, but seldom exceeds two or three feet. The pools between the rapids are on an average much longer reaches, in which there is little fall, and a greatly diminished velocity of the stream, which often, in them, flows so equably as to give rise to no ripple on the surface. They too have in them large stones, but fewer in number. The depth in them too varies greatly, from two or three to four or five feet. The rapids and pools in the Leochal are of a similar kind, but both much less deep in this smaller stream. The bed of this river has however, on the whole, a steeper descent, and owing to this there is more broken water and spray in the rapids. The character of alternating rapids and pools, in both streams, is owing to the varying hardness of the granitic and micaceous-schistose rocks in which their beds are formed. Where the rocks are hard, there is a rapid; where more friable, a pool. In the parts of the rivers observed, the original rocks themselves do not anywhere form the immediate bed of the stream. That, to the depth of two or three, or more, feet, is composed of the debris of these rocks, broken up and sometimes much waterworn, and reduced to the size of a very large gravel, by the action of the stream, but not so small as to deserve to be named sand. No part of the bottom is muddy.

On the night between the 31st of December 1834 and the 1st of January 1835, after the mean temperature of the air had continued for three days at 47° Fahr., and when there had been little frost in the season before, there commenced a hard frost, with a calm and perfectly cloudless sky, which continued with little abatement till the 5th of January, at 10 A.M. On the night between the 3rd and 4th, the temperature of the air was 23° Fahr.; and on the 4th, the bottoms of the rapids in the Leochal were seen coated in some places with silvery cauliflower-shaped clusters of ground-gru. I neglected at this time to examine the temperature of the water.

Between the 4th and 5th, the temperature of the air was down to 19° Fahr.; and on the 5th I examined the Don and the Leochal along half a mile of each, beginning the examination at half-past 8 o'clock A.M. The examination began at the bridge of

Alford, built of granite over the Don, in the middle of one of the rapids. At this rapid, the whole bottom, with the exceptions to be immediately stated, was covered with silvery gru, appearing from two or three to five or six inches deep. My attention was particularly directed to the exceptions, as throwing a clear light on the question of the radiation of heat from the bottom. Round each of the piers, and in front of the abutments of the bridge, there was a space quite clear of all frozen matter, excepting at a side of one pier under an arch, where a piece of very still water, caused by an obstruction at the bottom, was covered by clear sheet ice. On the south side of the river, two embanking walls, one up and the other down the stream, each twelve yards long, are built in a line with the water-courses of the abutment. Close to the bridge these walls are eight feet high from the bottom of the stream, but as they recede from the bridge the masonry slopes gradually to a lower level, till the extremities are little above the level of the water. The bottom in front of these walls was clear of ground-gru, as well as that in front of the abutments; but the breadth of the clear space in front of the walls narrowed gradually towards their extremities, in proportion as the masonry became lower, till at the extremity of the downward wall especially, which ends at a sloping gravelly bank, the gru came to the edge of the water. The space of the bottom clear of gru was about five or six feet broad at the high parts of the walls next the bridge; and the water runs on the place at the medium depth and velocity of the rapid. There was another clear space in the bottom of this rapid. About twenty-five yards above the bridge there is, in the middle of the stream, a piece of still water, caused by an elevated bed of gravel, just below it, over which the stream is very shallow. The still water, for an extent of two or three square poles, was covered with sheet ice, and that again covered by a very thin, but white, opake deposition of hoar frost. From under this ice the water, flowing rapidly over the gravel bed below, had no ground-gru for a space of eight or ten yards downwards.

Above this rapid, a pool of moderate stillness, about three or four feet deep, extends a hundred and fifty yards in length. Over the bottom of this there were scattered, in an irregular manner, many cauliflower-shaped clusters of silvery gru, most of them very small, and none that were observed covering more of the bottom than a square foot or two at one place. In the deepest and stillest part of the pool there were several tufts of water starwort, with sooty-coloured decaying leaves, forming the darkest-coloured objects seen at the bottom. These were all densely tangled with fringes of silvery gru. At the head of the pool, where the velocity acquired by the water in the rapid immediately above it was not yet greatly diminished, an appearance of a different kind presented itself. There are here several large stones in the bed of the stream, but none of them projecting above the water. On the faces of these opposed to the stream there were seen quantities of gru of a different aspect from that further down. It was not arranged in the same cauliflower shapes, but in angular masses, like wreaths of snow blown by the wind. It wanted, too, the silvery glance of the other, and had more the appearance of a pale ash-coloured mud. On

reaching it with the end of a pole, its consistency was found to be less firm; in fact, it was only a heap of detached uncemented spiculæ pressed against the stones, and retained there mechanically by the action of the water, in a certain modified state of its velocity. The source of these heaps of uncemented spiculæ will soon be noticed. This pool, as indeed was the case with all the pools in the river, had at its edges and in its little bays narrow pieces of surface-ice, extending a foot or two from the banks.

The rapid immediately above this, not unlike that at the bridge, was covered at the bottom with silvery gru, with one exception. The river was low at the time from long-continued deficiency of rain, and the water had deserted the south side of the channel, leaving many little pools among the stones, communicating more or less freely by irregular little currents with the main stream. The pools were covered over with sheet-ice, and that with a thin opake deposit of hoar frost like snow. In the little currents returning from under this ice there was no frozen matter.

At the head of this rapid there is a pool much deeper and stiller than that above the bridge-rapid already described. The depth is five feet, and the stillness such that, at many points of it, there is no ripple or wave on the surface. None of the silvery cauliflower-like ice was seen on the bottom here; but near the head of it, in a modified state of the current pouring in from the rapid above it, there were, on the faces of several large stones opposed to the stream, collections of uncemented icy spiculæ.

The source of these collections was very readily observed in a great rapid immediately above this. In that rapid the water has a much quicker descent than in the others referred to. It is about a hundred yards long, and cumbered with many large stones, over which, at many points, through its whole length, the water breaks with a great deal of spray. Here an immense quantity of gru occupied the bottom, impeding much the course of the stream. At the time of observation many pieces of this gru were seen edging up, and in some instances breaking quite away from the bottom, apparently by the increasing pressure of the water, as it became dammed back by the increase of the gru itself. This at least was the appearance, although there may have been another cause for the disengagement of it from the bottom, and that is, the impeding, by the imperfectly translucent gru, of that radiation of heat from the bottom which, I trust in conclusion to demonstrate, is the immediate chief agent in the whole phenomenon.

It is now to be observed, that a number of pieces of loose gru, the origin of which was so clearly ascertained at this last rapid, were floating down in all parts of the river. In passing through the rapids, they were broken into fragments, and, where the fall was violent, shivered into minute pieces. The larger pieces that remained after passing through the rapids floated at the surface, immediately as they got into the uniformly flowing currents at the heads of the pools; but the minuter ones, mixed with the water to all depths by the plunging whirls in the rapids, not being so speedily disentangled from their cohesion with the water, by the action of gravity, floated

for a greater distance immersed in the water, and were intercepted by, and mechanically retained against, the faces of the stones by the action of the stream at the heads of the pools. Further down, and in stiller water, where no such intercepted heaps were seen, their buoyancy had, no doubt, by degrees, overcome the cohesion and raised them to the surface; and in fact, in the still water, many minute icy fragments were floating in the surface.

Mr. KNIGHT, the celebrated botanist, quoted by M. ARAGO, has obviously, in part, but not completely, distinguished between the "frozen matter which reflected a silvery kind of whiteness," which covered the stones in the rocky bed of the river, and "floating spiculæ under water," which he found to "accumulate much more abundantly upon such parts of the stones as stood opposed to the current, where that was not very rapid, below the little falls or very rapid parts of the river."

In the smaller stream of the Leochal, the quantity of ground-gru was comparatively much more abundant, occupying the bottoms both of the pools and rapids in close masses, and in the latter, at many parts, forming such an impediment as to urge the water over its usual banks. But there were two remarkable exceptions. One of the pools flows close to the foot of a steep bank about fifteen feet high, and in the side next the bank there was little ground-gru. In a rapid, which at a turn of the river has an easterly course, there was a very dense fringe of *Phalaris arundinacea* standing, with its dense foliage of withered leaves, in the south edge of the water. Its height was four feet, and it extended fourteen feet in length along the stream. At the foot of it the bottom of the rapid was clear of ground-gru to the breadth of three feet.

The temperature of the air and water, at the time of these observations, was particularly ascertained. That of the air at sunrise, about an hour before the observations commenced, had been 23° FAHR.; but it was rising rapidly during their progress, and was at 36° FAHR. before their conclusion. The temperature of the water in the Don varied from 32° to 33° FAHR.; but the variation could not be distinctly traced as depending on the depth or velocity, as there was a temporary variation in the same place, both in the pools and rapids. At one of the small streams, returning from under the sheet-ice on the little pools at the edge of one of the rapids, the temperature was nearly steady at 33° FAHR. In the Leochal the temperature was nearly steady everywhere at 32° FAHR.

By 10 o'clock A.M. on the same day, a cloud obscured the whole sky, and at 2 o'clock P.M. the temperature of the air was 40° FAHR. At this time much gru rose from the bottom and floated down the streams of both rivers. The relaxation of the frost, however, was of very brief continuance. Before sunset the temperature of the air was again down to 31° FAHR., with a perfectly calm air and clear sky; and the clear sky continued till the evening of the 7th of January, the thermometer during the two intermediate nights being at 23°, and during the intermediate day at 26°.

The same parts of the Don and Leochal were again examined at 10 o'clock A.M. on

the 7th. In the Don the ground-gru now covered all the bottoms of the pools as well as of the rapids. It was of less depth in the deep still pool below the great rapid; but everywhere else it formed a great impediment to the stream, raising it so much above its former level that it covered deeply the pieces of sheet-ice formed at the edge on the 5th. New pieces of similar ice were now forming at the same places on the more elevated surface. The Leochal was still more impeded by the gru than the Don.

But, what is worthy of particular notice, the clear spaces of the bottom, at the piers, abutments, and embanking-walls of the bridge on the Don, and at the Phalaris grass in the Leochal, still continued so, but were now considerably narrowed in their lateral dimensions, the ground-gru having encroached upon them on the sides next the streams. The temperature of the air was 24° Fahr.; of the water, everywhere nearly steady at 32°.

Several circumstances occurred on some subsequent days which deserve to be noticed, as throwing light, by the contrast which they exhibit, on the phenomenon now under consideration. On the 8th of January there occurred a thaw, when the thermometer suddenly rose to 47° Fahr. The rivers were speedily cleared of ice and ground-gru, which last rose from the bottom and floated away with the stream. The atmosphere at the time was considerably clouded, with a brisk S.W. wind. On the 9th of January the temperature of the air fell to 36° Fahr.; and on the morning of 10th of January, with a temperature of the air at 29° Fahr., there was a fall of snow, of about an inch deep, which ceased by 8 o'clock A.M. The snow that fell into the rivers was observed to be entangled, and stuck fast, in irregular crushed masses, in many parts of the rapids; and there were collections formed of loose spiculæ of a muddy aspect, at the sides of the stones opposed to the streams, in the heads of the pools, where the velocity of the currents was intermediate between that of the rapids and that of the stiller parts of the pools; but there was no appearance on any part of the bottom resembling the symmetrical cauliflower-shaped ground-gru. On the evening of the 10th the temperature of the air fell to 23°, and continued at from 23° to 21° till the morning of the 12th, with a densely clouded state of the sky. During this time extensive sheets of surface-ice were formed on the pools of the Don, and many of the pools of the Leochal were quite frozen over, but the ground-gru was nowhere renewed; on the contrary, the masses of snow entangled in the rapids on the 10th disappeared to a great extent, obviously floating away in the stream. In this state of the river and weather, the collections of uncemented spiculæ, on the faces of the stones opposed to the streams in the heads of the pools, appeared in their places the same as before, neither increasing nor diminishing in size.

M. Arago, in his paper, refers to three circumstances, as partly, at least, explanatory of the formation of ground-gru in running water.

1st. The inversion, by the motion of the current, of the hydrostatic order, by which the water at the surface, cooled by the colder air, and which at all points of the tem-

perature of water under 39° Fahr. would, in still water, continue to float on the surface, is mixed with the warmer water below, and thus the whole body of water to the bottom is cooled alike by a mechanical action of the stream:

2nd. The aptitude to the formation of crystals of ice on the stones and asperities of the bottom, in the water wholly cooled to 32°, similar to the readiness with which crystals form on pointed and rough bodies in a saturated saline solution:

3rd. The existence of a less impediment to the formation of crystals in the slower motion of the water at the bottom, than in the more rapid one near, or at the surface.

There is no denying the justness of these three positions, and yet the slightest reflection teaches us that neither singly nor combined do they aid us in answering the main question before us, "Why is ice formed sometimes at the surface of running water, and sometimes at the bottom?" All the circumstances, or conditions, referred to by M. Arago, are present when ice, as most frequently takes place, is in the course of being formed only on the surface, as well as when the formation is going on at the bottom. Were we to admit them as an answer to our question, then running water ought always to freeze first at the bottom. But a most extensive experience teaches us that this is not the case. The illustrations of M. Arago, indeed, just and true in themselves, are not to be overlooked when we would investigate and explain the formation of ice either at the bottom or at the surface. They will serve to enlighten us greatly in both these events, but they have no exclusive relevancy to either, and we must therefore look out for another solution of the problem.

M. Arago, in his conclusion, does not present these three circumstances as a complete explanation; but he says, the reader may ask why he has not done so, and he answers to this, "that we have no observations which prove that this kind of ice is seen, until the temperature of the whole of the water is at zero" (centigr.); and that it is not certain that the little icy particles, seen by Mr. Knight, floating on a milldam, at the time ground-ice was forming in the stream, and which may have acquired in contact with the air a temperature below zero (centigr.), do not play an important part in the phenomenon which he has overlooked.

In regard to the former of these points, I cannot say what M. Arago would have deduced from it, had it been established in one way or the other. The observations made on the Don on the 5th of January show that the temperature of the whole water was not quite down to 32° Fahr. when the ground-gru was forming in large quantity. In regard to the latter, the little icy particles seen by Mr. Knight, the same condition belongs to them that belongs to the circumstances professedly adduced by M. Arago as explanations; that is, they occur as well when the ice is forming on the surface only as when it is forming on the bottom. They account well, however, for the collections of frozen matter seen by him at the sides of the stones opposed to the stream, in parts where its velocity had a certain modification.

And here I may advert to the explanation offered by the Rev. Mr. Eisdale, in his paper already referred to. From the information he received, he was led to believe

the ground-gru does not occur but when there is a hoar frost on the ground; and he explains the ground-gru to be particles, or crystals as he afterwards names them, of hoar frost precipitated into the water, retaining there the shapes in which they descended, brought into contact with the rocks by the agitation of the water, and forming nuclei for the accumulation of ground-gru. Could it be proved that such crystals are precipitated into the water, they would serve no more for explanation than the icy particles of Mr. KNIGHT. We have learnt, indeed, from travellers in high northern regions, that, in certain states of cold and moisture of the air, such crystals, as Mr. EISDALE assumes, are there seen and felt floating in it; but nothing of that kind was observed in January last; and when Mr. EISDALE, from the existence of spiculæ of hoar frost on the ground, would infer the like may be formed in the air to fall into the water, he neglects to take into the account, that the spiculæ of hoar frost have not fallen from above, but that their symmetrical arrangement, round on all sides of the bodies on which they are found, and their slow increase, prove they have been deposited on their places by a gradual deposition of invisible watery vapour, owing to the substances to which they are attached being cooled below the temperature of the surrounding air, by the radiation made known to us by the experiments of Dr. WELLS. Besides this we have to remark, that the ground-gru sometimes takes place, agreeably to the information of one of Mr. EISDALE's own correspondents, in a windy state of the atmosphere, at which time no hoar frost is seen.

The interesting experiments of Dr. WELLS just referred to enable us to give, after all, a very satisfactory explanation of the ground-gru; and Mr. M'KEEVER, quoted by M. ARAGO, had gone far to illustrate it by means of them, although he had overlooked some conditions necessary to be taken into the account for a complete explanation. M. ARAGO, however, entirely rejects the explanation of Mr. M'KEEVER, and it is fair to set down the terms in which he does so.

After having shown that the ground-gru cannot be explained by the action of the moon*, according to the sailors, nor by the friction of running water producing more heat at the surface than at the bottom, nor by referring its source to the smaller tributaries of the streams, nor to different layers of ice formed at the several surfaces, when the water in the river, from whatever cause, is in a state of varying fullness, all of which have been assigned as causes of the ground-gru, M. ARAGO proceeds:

"We come now to Mr. M'KEEVER, who, confining himself closely to the most subtle principles of the theory of heat, has not on this account been more fortunate than his predecessors. According to this author, 'the rocks, stones and gravel, which generally cover the bottom of rivers, have powers of radiation superior to those of mud, perhaps on account of their peculiar nature, but chiefly because they

* This explanation of the sailors is a confirmation of what I have stated, that the gru never appears but under a clear sky. The constant observation of the sailors has associated, in their minds, the shining of the moon with the ground-gru; but the moon never shines, to excite great attention, but in a clear sky.

have rough surfaces. Thus rocks in large or small masses will become much cooler in consequence of radiation: when the atmospherical temperature is very low, they of course freeze the water which touches them.' It is unnecessary to examine here whether heat radiates through a thick layer of water, as Mr. M'KEEVER supposes, as the most simple observation is sufficient to overthrow it. Where is the person who has not observed that the strong radiation, which the Irish philosopher admits, would be more plainly manifested, or as completely, in still water than in running water? but no one has seen a piece of still water frozen at the bottom*."

But there is nothing more easy of experimental proof than that heat radiates through water. I do not mean, however, to vindicate the reasoning of Mr. M'KEEVER respecting the more powerful radiation of it from stones than from mud. His reasoning respecting that matter is, on his own part, conjectural, to explain the readier formation of gru on a stony or gravelly bottom; but the gru also forms on a muddy bottom, a fact which M. ARAGO notices, when he brings the attachment of mud to the under side of the floating flakes as a proof that they have been formed at the bottom. Mr. M'KEEVER was driven to his conjecture from having overlooked the more complete and sudden inversion of the hydrostatic order that takes place over stones than over mud; which last is deposited only in places where the water has a stiller and more equable motion. In such places the ground-gru is later in forming, and therefore is more rarely seen; and it is doubtful whether Mr. M'KEEVER had a proper opportunity for noticing it in them.

But to return to the main point which we have here to maintain in opposition to the reasoning of M. ARAGO, the radiation of heat through a body of water. When we construct an achromatic object-glass for a telescope, it does not the less remain a burning-lens when we have included in it a transparent fluid, and no experiment has proved that were the fluid water the case would be altered. We are aware of the danger that has been incurred of setting fire to an apartment by an ornamental glass globe filled with water, and placed in the sun at a window. But as I cannot particularly refer to circumstances of time and place of the cases now mentioned, I made an experiment on the subject with such apparatus as I could find readily at hand, having no access to better in a remote country place†. In a room, of which the temperature was 50° FAHR., a semiglobular tumbler filled with water, containing about a pint and a half, was placed inside a window, in the rays of the low but clear winter sun. The bulb of a thermometer, which had been previously placed in a similar situation till it rose and remained steady at 61°, was shifted into the brightest part of the fan-shaped focus of rays, into which the light was refracted through the tumbler. In this position it was raised in four minutes to 72°. It was again shifted into the unconcentrated rays passing through the window, when it fell, but more

* Edinburgh New Philosophical Journal, vol. xv. pp. 132, 133.

† It may seem absurd to have had recourse to experiment in a case so plain; but the procedure seemed, at the same time, indispensable, to meet reasonings promulgated with the authority of such a distinguished name.

slowly than it had risen; and the experiment was repeatedly renewed with similar results, leaving no doubt that the heat, like the light, radiated through, and was refracted by the water. If the fact is so in regard to the radiation of heat through a mass of water four or five inches thick, where ought we to set the limits of thickness of the mass through which it cannot pass? Obviously only where the thickness is so great, that the aggregation of the fluid, and of its minute impurities, prevents the transmission of light, as in the deeps of the sea, but not within the ordinary depths of our clear streams.

Of the effect of radiation in cooling down the surface of the ground, and substances placed upon it, during a clear sky, we cannot give a more lucid account than that of M. Arago, in his paper "On the supposed Influence of the Moon on Vegetation." "No one had supposed," says he, "before Dr. Wells, that terrestrial substances, excepting in the case of a very rapid evaporation, may acquire during the night a different temperature from that of the surrounding air. This important fact is now well ascertained. On placing little masses of cotton down, &c. in the open air, it is frequently observed that they acquire a temperature 6°, 7°, or even 8° centigr. below that of the surrounding atmosphere.....These differences of temperature between solid bodies and the atmosphere only rise to 6°, 7°, or 8° of the centesimal scale, when the sky is perfectly clear. If the sky is clouded they become insensible." This lucid statement, however, requires one modification; for the greater cooling of the solid substances, under a clear sky, takes place not only during the night, but also during the day, in places not directly exposed to the sun's rays.

This radiation, as it passes freely through the transparent atmosphere, may, as we learn from the above experiment, pass also through the transparent water, to cool down the solid substances at the bottom below the temperature of the surrounding fluid. That fluid is permeable to radiating heat as well as the atmosphere. The application of the thermometer, in the hands of Dr. Wells, instructed us regarding the cooling of the surface of the ground; but the water of a river, placed under the very same condition of a clear sky, fluid above and freezing below, is a great natural thermometer, teaching us that a corresponding cooling is going on on the surface of the solid opake substances of the bottom. In fact, if we may so speak, the phenomenon of the ground-gru is the result of an experiment in the water, entirely similar to that of Dr. Wells on the land, performed by nature on a large scale, and presented to us for our interpretation and instruction. And when we look back to the observations made in the month of January, we find the results of the modifications of this great natural experiment corresponding with those of similar modifications of the experiment on the dry land.

The cooling of the surface of the ground by radiation, discovered by Dr. Wells, takes place only under a clear sky. It is therefore greatly modified on parts of the ground screened from a part of the sky by opake objects, as walls, trees, hedges. In illustration of the extent to which a screening or shading body, near at hand,

modifies the radiation, I shall detail some observations I made on the 7th of January last, incidentally in the first instance, but then extended, in reference to the observations on the ground-gru, which I was making at the time. Having occasion that day to dig into recently hoed ground, in the middle of a garden, remote from shade, the soil was observed to be frozen to the depth of four inches, by the clear frost, which had continued from the 1st of January, with the trifling intermission above mentioned. On digging into similar ground at the north base of a wall six feet high, the soil was found, close at the foot of the wall, frozen to the depth of only half an inch; at a foot distance from it, about an inch; at two feet, little more; and it was only at the distance of ten or twelve feet that it was frozen hard to the depth of three inches. A similar modification of the effect of radiation was observed in the shade of trees. Under the Scotch fir the soil, slightly covered with decaying herbage, was not at all frozen; although in similar ground similarly covered, but remote from shade, it was hard frozen to the depth of two or three inches.

Now the ground-gru in the rivers was modified in a way strictly similar by the effect of shade. The bridge of Alford, over the Don, is happily situated for illustrating this, being on one of the rapids, where the ground-gru is earliest and most abundantly formed. While the other rapids, and the unshaded parts of this one, were quite occupied by gru on both the 5th and 7th of January, spaces in the shade of the masonry at this bridge were quite clear of it. It cannot be admitted as an explanation of this fact, that heat may have been there laterally transmitted to the water by contact with the piers and walls; for if this took place, why then did the clear spaces on the bottom narrow gradually towards the low extremities of the embanking walls? Besides, the transmission of heat laterally had not hindered the formation of surface-ice, in contact with a pier, on a piece of still water under one of the arches. The modification of the radiation by shade was also exhibited in the absence of all gru on the bottom, along the foot of the dense tuft of Phalaris grass in the Leochal, where there could be no more transmission of heat laterally, than at the general line of the grassy banks of this stream.

The water, too, returning warmer from under the surface-ice, on the little pools at the edge of one of the rapids, is another instance of the modification of the radiation by shade. The thin white opake covering of hoar frost on the ice prevented radiation, at least in a great measure, and the heat of the bed of the river, in the course of continual transmission upwards, from strata not yet cooled to much depth by the frost, finding no outlet by the radiation, was expended in heating the water by contact.

There was another phenomenon observed on the 5th of January, (although no longer seen on the 7th, being then concealed by the immense formation of gru,) which can be readily explained by the admission of the radiation of heat through the water, and therefore goes to support the justness of the theory. The tufts of water starwort, in the deepest and stillest parts of one of the pools, were the darkest-

coloured objects seen at the bottom, and they were fringed in every part with spiculæ of gru, at a time while it yet occupied little of the bottom of this pool. The experiments of Boyle, Franklin, Rumford, Leslie (although he denies the conclusion himself), Davy, and Stark appear too uniform in their results to leave any doubt remaining, that dark-coloured bodies both absorb and radiate heat more freely than those which are light-coloured. It is in consistency, then, with an ascertained law of the radiation of heat, that the very dark-coloured tufts of the water starwort should have been the first bodies in the pool cooled to a very low temperature, and of course first covered with gru.

In arguing the whole question, let us not forget to assign a proper value to the illustrations of M. Arago. The first of them suggests a ready and satisfactory answer to one of the objections which he brings against the theory of radiation, which is, that the effect of it should be as readily manifested in still as in running water, and yet no one has seen a piece of still water frozen at the bottom*.

In still water, that hydrostatic order, which M. Arago has so well illustrated as belonging to water when reduced to a temperature under 39° Fahr., has free play to establish itself, and is not inverted by the mechanical action of a stream. When the temperature of a body of water is under 39°, then the coldest portions of it are the lightest, and naturally rise and float on the surface. When in a still pond the water nearest the bottom has been cooled below the general temperature by contact with the solid materials cooled by radiation, it is displaced by the heavier warmer water above. Hence ice forms first on the surface by the meeting there of both the cold of radiation and that acquired by contact with the incumbent cold atmosphere.

M. Arago's illustrations also furnish us with a satisfactory explanation of the curious facts, that the ground-gru makes its first appearance in the more rapid and agitated parts of the stream, and begins to show itself on the bottoms of the stiller parts, and to accumulate there in quantity, only after a longer continuance of the clear frosty weather. In the rapids the hydrostatic order is overturned, and the colder, which is also the lighter, water not only mixed with the warmer below, but, at the whirls of the greatest rapids, brought suddenly, without much mixing, into direct contact with the bottom, cooled still lower than itself by radiation. If the water is at the temperature of 32° Fahr. it can give out no heat to the colder bottom

* There is an exception to the universality of this position, which, although rare, I have sometimes witnessed; and as the phenomenon is in accordance with the theory of the radiation of heat from the bottom, it deserves notice. In little ponds of a foot or two deep, dug to obtain the materials for building or agricultural purposes, of which there are many examples in this neighbourhood, after they have been covered, owing to hard and long-continued frost, by a thick sheet of ice, that is sometimes nearly melted off, and the remaining fragments driven to the lee side by a strong westerly gale of high temperature. Such a gale, in this climate, frequently, towards its conclusion, shifts to N.W., when the temperature of the air falls again below the freezing-point of water, with a generally clear sky. In such peculiar circumstances the little ponds are suddenly filled with gru, commencing at, and shooting up from the bottom. The whole water is here at 32° Fahr. when the gru begins forming, and the hydrostatic order is deranged by the wind.

without part of it being converted into ice, the spiculæ and crystals of which find a solid body for their attachment at the very point where the heat is given out*.

But while in this manner we can explain some of the incidents, may it not be held, as above demonstrated, that the chief cause of the ground-gru is the radiation of heat from the bottoms of the rivers? Every branch of the phenomenon is of easy explanation when we admit the radiation; and among the rest a circumstance to which I have yet made no reference, and that is, the disappearance at the bottom of the water of the immense quantity of heat, 140° of FAHR., which constitutes the caloric of fluidity disengaged, when water at 32° FAHR. is converted into ice at the same temperature.

The answer to our original question then is, That ice is formed sometimes on the surface of running water, and sometimes at the bottom, because frost sometimes takes place with a clouded sky, which is incompatible with radiation of heat from the bottom of the stream, and sometimes with a clear sky, when that radiation takes place through the water, in the same manner as the experiments of Dr. WELLS prove it goes on, under a like sky, through the atmosphere. The bottom is by this cooled down below the freezing point of water, before the water itself; ice is formed on it, and its detachment by transmitted heat from below prevented, as long as the radiation continues.

*. We may observe also, that there is a local source of greater cold of the water in the rapids, in its being brought into more active and extensive contact with the air by the sharp ripple and spray.